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PACKAGING TO IMPROVE COOK-OFF CHARACTERISTICS OF 155-MM PROPELL--ETC(U)
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MEMORANDUM REPORT ARBRL-MR-02850

PACKAGING TO IMPROVE COOK-OFF CHARACTERISTICS OF 155-MM PROPELLING CHARGES

by

Harry J. Reeves
Leonard Teitell

July 1978

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER (14) MEMORANDUM REPORT ARBRL-MR-02850	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER (9)
4. TITLE (and Subtitle) (6) PACKAGING TO IMPROVE COOK-OFF CHARACTERISTICS OF 155-mm PROPELLING CHARGES.		5. TYPE OF REPORT & PERIOD COVERED Final rept.
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) (10) Harry J. Reeves [redacted] Leonard Teitell		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS USA Ballistic Research Laboratory ATTN: DRDAR-BLV Aberdeen Proving Ground, MD 21005		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS (16) 1L662618AH80 (17) 11 1L662603AH18 11
11. CONTROLLING OFFICE NAME AND ADDRESS US Army Armament Research & Development Command US Army Ballistic Research Laboratory ATTN: DRDAR-BL Aberdeen Proving Ground, MD 21005		12. REPORT DATE (11) JUL 1978
		13. NUMBER OF PAGES 41
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) (12) 38p.		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

(18) SBIE (19) AD-E430 094

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

The assistance of Messrs. Leigh, Smyth, Martin, Pettigrew, and Ewing in conducting the large scale field tests is gratefully acknowledged.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Ammunition Cook-Off
Propellant Cook-Off
Ammunition Fires
Fire Tests Ammunition
Protective Packaging Ammunition
Fire-Retardant Packaging
Thermal Insulation

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Explosions, progressive cook-offs and fires causing severe damage to equipment and personnel have been reported to occur when large quantities of palletized propelling charges came under attack by enemy forces. This report presents the results of laboratory tests, small and large scale field tests designed to evaluate the effectiveness of modified packaging in improving the cook-off characteristics of 155-mm propelling charges. The results of these tests show that modified packaging can be used to improve the cook-off characteristics of separate-loading propelling charges and limit the extent of damage to multi-pallet stores subjected to direct hits by large caliber HE projectiles.

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I. INTRODUCTION

An analysis of fires at ammunition supply points showed that packaging materials were the main cause of the spread of fires. In the case of packaged fixed and semifixed artillery ammunition, the external wooden box was the major contributor to the ammunition fires.

In 1975, the Ballistic Research Laboratory and the Pitman-Dunn Laboratory completed a joint study* designed to evaluate the effectiveness of fire-retardant packaging for artillery ammunition. In support of this effort, a series of fire tests were conducted on stacks of 81-mm Mortar, 90-mm TP-T Gun, or 105-mm HE Semi-Fixed Howitzer ammunition packaged in fire-retardant materials, with the objective of determining whether fire-retardant packaging materials prevent fire spread when the ammunition itself acts as the ignition source. It was concluded, as a result of these tests, that fire-retardant packaging can be used to protect stacked ammunition by eliminating the spread of fire when one or more rounds in the stack is ignited.

The scope of this effort has been expanded to address the hazards associated with the storage of the propelling charges used with 155-mm separate-loading ammunition. Explosions, progressive cook-offs and fires causing severe damage to equipment and personnel have been reported to occur when large quantities of propelling charges came under attack by enemy forces.

Described in this report are laboratory small and large scale field tests designed to evaluate the effectiveness of modified packaging in improving the cook-off characteristics of 155-mm propelling charges.

The overall test objective was to demonstrate that the vulnerability of large stores of palletized 155-mm propelling charges can be reduced significantly, by improving their cook-off characteristics, when burning propellant acts as the heat source. No attempt was made to address the problems associated with the vulnerability of propelling charges containing multiple base propellants where damage can be propagated by blast overpressures.

II. APPROACH AND TEST METHODS

Current US Army assets include 155-mm, 175-mm, and 8-inch weapon systems. Each of these systems use separate-loading ammunition. In separate-loading ammunition, the separate components --- projectile, propelling charge and primer --- are loaded into the weapon separately.

L. Teitell and H. Reeves, "Fire Retardant Packaging for Artillery Ammunition," USA Ballistic Research Laboratory Memo Report No. 2490, August 1975. (AD #B009495L)

Separate-loading projectiles are generally shipped with nose (lifting) plugs, which are replaced in the field with fuzes. The projectile is inserted into the breech and rammed so that the rotating band seats in the forcing cone of the weapon. The propelling charge, usually in one or more cylindrical cloth bags held together with tying straps, is placed in the chamber immediately to the rear of the projectile. After the breechblock of the weapon has been closed and locked behind the charge, the primer is inserted into the firing mechanism of the breechblock. The propelling charges for these separate-loading rounds are packed in a cylindrical metal container and are normally transported and stored on wooden pallets.

In lieu of evaluating the effectiveness of improved packaging for each separate-loading propelling charge in the inventory (see Table I), tests were conducted using the M4A2 charge for the 155-mm Howitzer. It was tacitly assumed that the effectiveness of improved packaging could be evaluated independent of charge type, e.g. propellant weight and propellant chemistry. The M4A2 propelling charge, see Figure 1, is a multizone charge, used by both the towed and self-propelled 155-mm Howitzer Cannon Systems. In addition to the protection provided by a metal shipping container, cushioning materials in the form of corrugated paperboard and either curled hair, vegetable fiber or wooden blocks are provided to insulate the cloth-covered propelling charge from the metal shipping container.

Packaging modifications evaluated in this study included painting the exterior surface of the metal shipping containers and chemically treating the cushioning materials so that they exhibited fire-retardant properties.

The test methods employed in the laboratory, small scale and large scale tests, are described in the following sections.

A. Laboratory Tests

The laboratory testing phase of this study was designed to evaluate 1) the heat insulating qualities of fire-retardant treated corrugated paperboard, 2) the heat insulating properties of fire-retardant intumescent paint, and 3) the insulating property of cushioning materials. In these tests a sheet of steel was used to simulate the cylindrical steel container used for packaging 155-mm propelling charges. The thickness of the steel plate, 1.68-mm, was approximately the same as the thickness of the steel walls of a shipping container. A Fisher blast burner, fed with propane and compressed air, was used to heat the lower surface of the steel plate. Test results were recorded in terms of the time required to ignite nine IMR 5010 propellant grains placed on the upper surface of the steel plate, i.e., the side opposite the heat source.

Table I. Propelling Charges for Separate-Loading Artillery Ammunition

All Charges Categorized As Active - May 1977

Calibre	Dsg	Propellant			
		Type	Web[1]	Gran[2]	Weight[3]
155-mm	M3	M1	.0165	SP	2.49 (88.0)
	M3A1	M1	.0157	SP	2.48 (87.5)
	M4A1	M1	.0336	MP	5.98 (211.0)
	M4A2	M1	.0360	MP	6.02 (212.4)
	M72 (XM206)	M1	.0165	SP	3.27 (113.8)
	M72 (XM207)	M30	.074	MP	7.86 (277.2)
	M197	M1	.0426	MP	7.35 (259.2)
	XM164	M1	.016	SP	3.81 (134.4)
	XM201E1	M30A1	.054	MP	7.82 (276.0)
	XM203E2	M30A1	.078	MP	11.88 (419.0)
175-mm	M86A2	M6	.0776	MP	26.17 (923.0)
8-Inch	M1	M1	.0171	SP	5.93 (209.1)
	M2	M1	.043	MP	12.76 (450.2)
	M80	M6	.055	MP	-
	M188	M30A2	.085	MP	16.91 (596.5)
	M188E1	M30A2	.085	MP	18.88 (666.0)
	XM161	M17	.079	MP	15.65 (552.0)

1. *Web is the minimum distance, in inches, between any two specified burning surfaces of a propellant grain.*
2. *SP: Single Perforated, MP: Multi-Perforated.*
3. *Weight in kilograms and (ounces).*

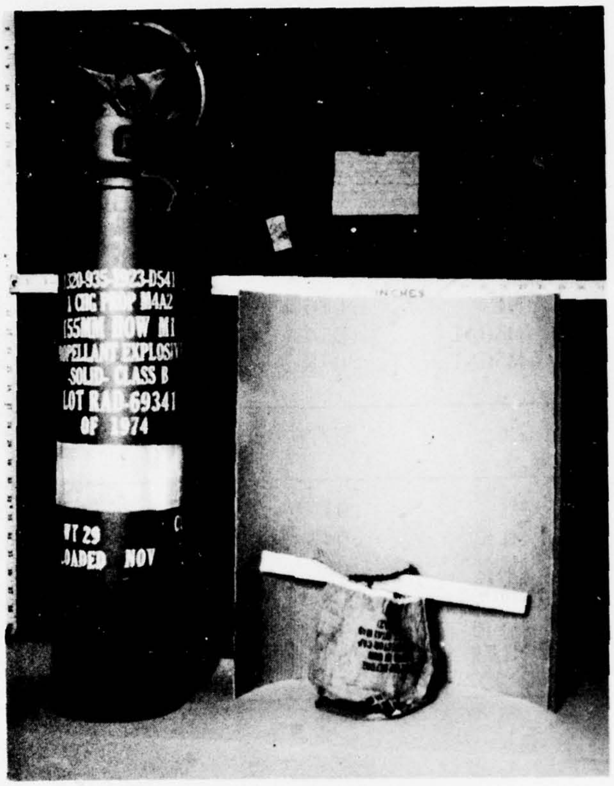


Figure 1. M13 Series Container and Inner Wrap Material Used to Package the 155-mm M4A2 Propelling Charge

B. Small Scale Tests

The small scale tests were donor-acceptor tests designed to evaluate the effectiveness of 1) fire-retardant corrugated paperboard and cushioning materials, 2) intumescent paint, and 3) a combination of both techniques in improving the cook-off characteristics of M4A2 propelling charges when they are subjected to a burning propellant environment.

The closing lids of shipping cans containing the donor charges were removed, the exposed propellant ignited, and the donor cans positioned and secured so that the flame from the burning propellant impinged on the sidewall of the acceptor charges. A typical test setup is shown in Figure 2. The number and type of donor charges, the standoff distance between the open end of the donor cans and the acceptor cans, and the number and configuration of the acceptor cans were varied until a configuration was tested that terminated in a cook-off reaction of an unmodified acceptor charge. Tests were then conducted using modified acceptor cans.

Modifications of the M4A2 acceptor charges included 1) painting all exterior surfaces of the metal shipping cans with two or three coats of an epoxy intumescent paint (MIL-C-46081A), 2) dipping the corrugated paperboard inner wrap in an aqueous solution containing 17.5% diammonium phosphate and 2.4% phosphoric acid (pH 7.0), and replacing the cushioning materials located at the ends of the cans with fire-retardant rubberized curled hair material.

C. Large Scale Tests

Groups of 40-round pallets, see Figures 3 and 4, were used in the large scale testing phase. Only those cans located in the center of the 16-pallet target array contained propellant. The remainder of the shipping cans were sand filled to simulate the confinement that would be afforded by a larger target array. The target arrays were constructed inside a large chain link enclosure to satisfy safety requirements; see Figure 5.

Target arrays were subjected to the blast and fragmentation effects of a statically detonated 81-mm mortar projectile. The mortar projectile was positioned vertically, fuze up, between two pallets of loaded (propellant-filled) shipping cans.

In addition to a baseline test using a target array with standard M4A2 propelling charges, two firings were carried out against a target array with propelling charges in modified shipping cans. Other modifications included using either metal pallets or pallets constructed with fire-retardant lumber and replacing any combustible dunnage with fire-retardant lumber.

In addition to 16-mm motion picture coverage, each test was monitored/documented using a closed circuit TV system.

Figure 2. Small Scale Test Configuration Used in Tests 10-13

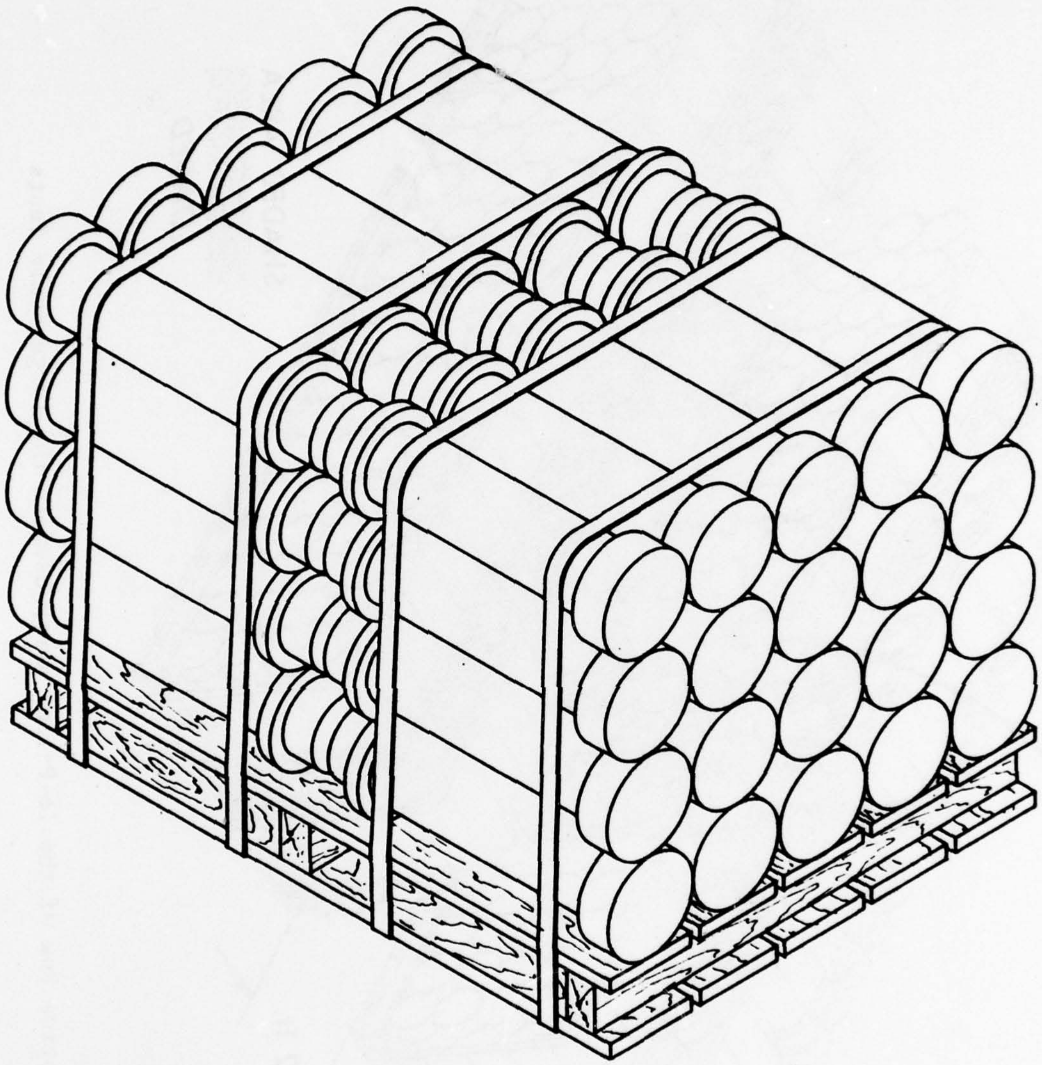


Figure 3. 40-Round Pallet Used in Large Scale Tests

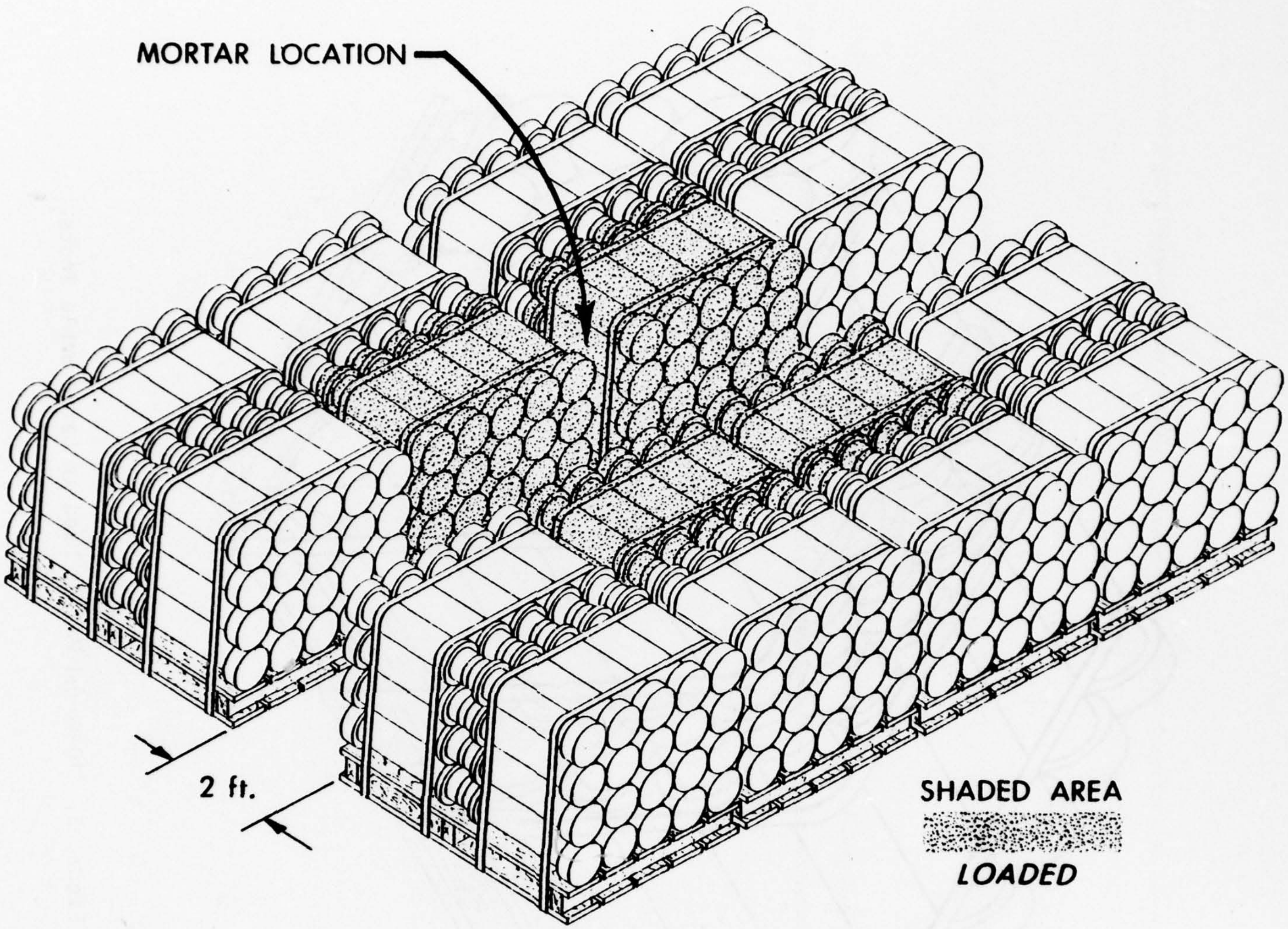
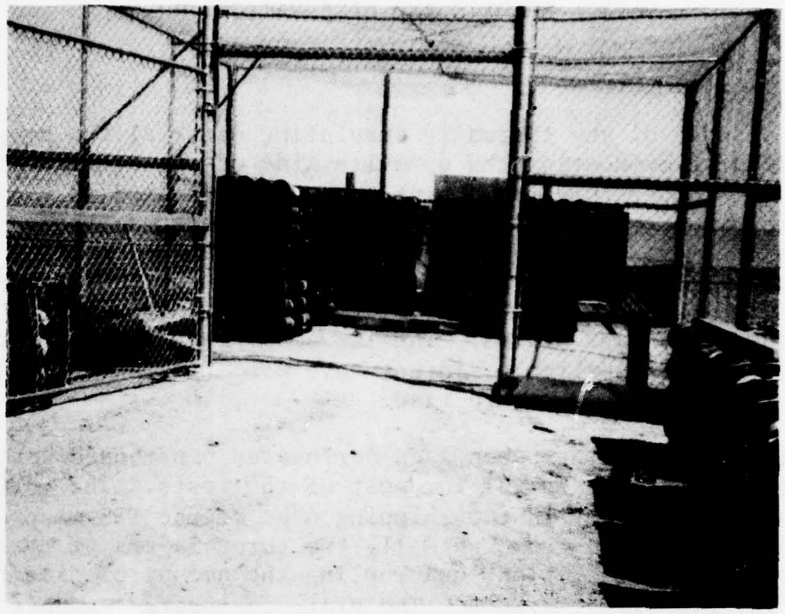
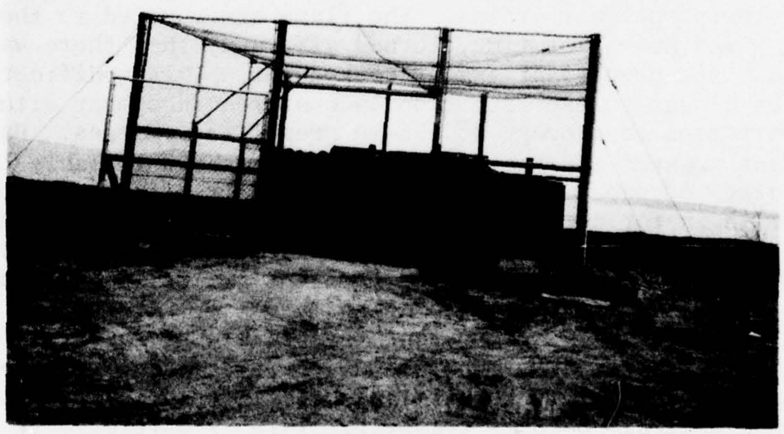


Figure 4. Bottom Row of the 16-Pallet Array Used in the Large Scale Tests



Partially Constructed Array



Full Array

Figure 5. 16-Pallet Array in Chain Link Enclosure

III. RESULTS AND OBSERVATION

A. Laboratory Test Results

In the absence of any thermally insulating material the propellant grains ignited after heating the opposite side of the steel plate for 10.5 seconds. Temperature indicating lacquers were used to monitor the rate of temperature rise, and with heating of bare steel these showed 371°C after 11.8 seconds; 427°C after 17.7 seconds; 538°C after 21.1 seconds; and 649°C after 27.4 seconds. Attachment of thermocouples interfered with the insulating properties of materials used to protect thermally the propellant grains. The infrared, non-contact pistol thermometer that was available did not have a fast enough response time to monitor the rapid temperature rise.

Three layers of c-flute open face corrugated paperboard were used as the thermal insulating material for most of the tests. The corrugated board is used as a filler in the shipping cans of the 155-mm propelling charges. As can be seen from Table II, the three layers of corrugated board offer thermal protection, quadrupling the amount of time required to set-off the propellant grains. The plain corrugated catches on fire and the flame of the burning paperboard ignites the propellant grain. The fire-retardant treated corrugated does not actually support a flame, but the paperboard thermally decomposes, until there is a hot char which ignites the propellant grains. The amount of protection in terms of time may appear small, but in the real life situation, the shipping cans of a propelling charge would be exposed to a propellant fire of only about 30 seconds' duration.

The experimental procedure was modified to obtain data on the amount of heat that could be applied to the steel plate without subsequent ignition of the propellant grains. The flame was applied to the steel plate for a given amount of time, turned off, and, then there was observed whether or not the propellant grains cooked-off. This modification appears to be closer to the situation encountered in combat situations with transportation or storage of 155-mm propelling charges. Data for fire-retardant treated corrugated paperboard is shown in Table III. Values for asbestos paper, which is not physically affected by the heating, are shown for comparison. It appears that there is a minimal amount of heating that has to take place, and once that has been accomplished the time to ignition of the propellant grains is dependant upon the thermal diffusivity of the insulating material. Additional application of heat is relatively unimportant in determining the time for a rise to cook-off temperature. The use of fire-retardant treatments on the corrugated serves mainly to eliminate flaming, so ignition of propellant occurs entirely by heat transfer. This is particularly shown in Table IV where heat absorbing powders of hydrated inorganic chemicals were placed between the layers of corrugated. The lack of burning markedly extended the time to ignition of the propellant grains when the corrugated had been treated with a fire-retardant.

Table II. Insulating Quality of Single Faced Corrugated Paperboard Measured by the Time to Ignition of a Single Base Propellant Upon the Application of Heat to a Steel Plate Support

Number of layers of corrugated	Time of heating until ignition, seconds	
	Plain corrugated	Fire-Retardant treated corrugated*
0	10	-
3	46	63
6	74	102
8	95	162

Each layer of corrugated was sprayed with a solution of ammonium phosphate at pH 6.7 so that the paperboard contained 32% of the fire-retardant.

Table III. Heat Insulating Qualities of Fire-Retardant Treated Corrugated Paperboard, Based on Ignition of Propellant Grains

	Heat applied until ignition occurs, time to ignition, seconds	Longest time heat applied without ignition, seconds	Shortest time application resulted in ignition, seconds	
			Time heat applied	Time to ignition
Metal alone	10.3	9.8	-	-
Untreated corrugated, 3 layers	43 to 46	35	40	50.4
Asbestos paper, 3 layers	113	40	45	113
Corrugated with 19% ammonium phosphate,* 3 layers	63	40	45	73
Corrugated with 5% ammonium aluminum sulfate,* 3 layers	47	30	35	65
Corrugated with Ocean Chemicals #712 1-2 min. dip, 3 layers	-	50	55	123

* *Applied by spraying an aqueous solution.*

Table IV. Effects of Inclusion of Hydrated Powders Between Layers of Corrugated on the Time to Ignition of a Single Base Propellant During the Application of Heat

	Heat applied until ignition occurs, time to ignition, seconds	Longest time heat applied without ignition, seconds	Shortest time heat applied with ignition, seconds	
			Time heat applied	Time to ignition
Untreated corrugated, 3 pieces	43	-	-	-
Untreated corrugated, 3 pieces with 44-48 g ammonium alum	83	60	65	90
Untreated corrugated, 3 pieces with 32-35 g alumina trihydrate	80	50	55	87
Treated* corrugated, 3 pieces with 32-35 g alumina trihydrate	101	50	60	144

* *Sprayed with solution so that the corrugated paperboard contained 19% ammonium phosphate.*

Laboratory evaluation was also done on the use of fire-retardant intumescent paint coated on the side of the steel panel heated by the burner. Results are shown in Table V. With the double system of three layers of corrugated paperboard (as is usually used as a filler) as a thermal insulating material, the addition of the outer intumescent coating offers comparatively good protection to preventing cook-off of the propellant. It was noted that the protection given by the intumescent paint depends upon the type of flame and the distance of the flame source to the paint. The intumescent char is, as would be expected, very light and easily dislodged by a flame jet.

There have been indications in vulnerability tests of packaged propelling charges of 155-mm ammunition that the cushioning materials, placed in the ends of the canisters, would smoulder for a relatively long period of time and eventually cause ignition of the propellant. Consequently, tests were run to determine whether fire-retardant treatments applied to the cushioning materials would decrease the cook-off hazard in a fire situation. Fire-retardant rubberized curled hair cushioning material was obtained from Blocksom and Company. The fire-retardant curled hair had a flame spread value under 25 when tested by the National Bureau of Standards using the 25 foot Tunnel Furnace test. The fire-retardant curled hair cushioning material was found to be self-extinguishing when removed from the flame of a burner. In comparison, vegetable fiber cushioning material removed from canisters of 155-mm propelling charges continues to burn, after removal of a flame, to a char that retains its original configuration.

The heat insulating properties of the fire-retardant curled hair werecompared to those of the vegetable fiber cushioning die cuts removed from canisters of propelling charges with respect to cook-off of propellant. The method used was the same as had been used for testing the heat insulating properties of the open face corrugated paperboards that are present as lengthwise spacers in the canisters of propelling charges. The cushioning material was placed between propellant grains and a steel plate heated by a fire from a propane fed Fisher blast burner, and there was recorded the time to ignition of the propellant grains. The fire-retardant curled hair was found to be no better than the regular vegetable fiber cushioning material in preventing, or delaying, cook-off of propellant. The times to ignition of propellant, for one-half inch thick cushioning materials, are shown in the accompanying Table VI. Even though the fire-retardant curled hair did not burst into flame as did the vegetable fire, sufficient heat was transmitted through the curled hair to bring the propellant to cook-off temperature in about the same amount of time as the flame from the vegetable fiber which ignited the propellant.

Table V. Heat Insulating Properties of Fire-Retardant Intumescent Paint (MIL-C-46081) in Delaying Cook-off of Propellant Grains

No. of coats of paint	Thickness of paint, mm	Weight of paint coating on panel, kg/m^2	Time to ignition,* seconds
		No corrugated	
2	.285	.337	37.3
3	.450	.553	47.6
4	.507	.685	57.8
		3 layers corrugated (not fire-retardant treated)	
2	.267	.316	99.0
3	.409	.510	202.6
4	.526	.658	274.2

*Determined by the time from application of heat to the painted surface of a steel panel to the ignition of a single base propellant (IMR 5010) centered on the back of the panel or on corrugated centered on the back of the panel. Time to ignition of propellant on an unpainted panel is 10-11 sec.

Table VI. Insulating Property of Cushioning Materials for Packaging as Measured by Time to Ignition of Single Base Propellant Upon Heating of a Steel Plate Support

	Vegetable Fiber (from Packaged 155mm Propelling Charges), 1/2 Inch Thick	Fire Retardant Curled Hair 1/2 Inch Thick
Time to ignition, in seconds, when heat is applied until propellant burns.	45	46
Maximum time, in seconds, heat was applied without ignition of propellant.	40	37
Minimum time heat had to be applied for propellant to ignite.		
Time of heating in seconds.	42	39
Time that propellant ignited, in seconds	131	44

Despite its superior fire resistance in terms of self-extinguishing characteristics, the fire-retardant curled hair was no better than the vegetable fiber with regard to preventing, or delaying, the cook-off of grains of single base propellant. In the previous tests, access to oxygen was limited to the surrounding air. Under these conditions, of relatively limited oxygen, the vegetable fiber smoulders and the propellant are not ignited by a flame from burning material. It was decided to repeat the test except to increase the access to oxygen so that a blaze may occur. The test was run as before, placing a piece of cushioning material 127 x 127-mm and 12.7-mm thick upon a steel plate that was heated from below by the flame from a propane fed Fisher burner. There was recorded the time to ignition of nine propellant grains, fastened together, that were positioned on the cushioning material. The heat from the steel plate had to transfer through the cushioning material to cook-off the propellant, or blazing cushioning material could ignite the propellant. The test was modified to include a stream of air, 4×10^{-4} cu meters per second, flowing from a 65-mm diameter funnel placed 75-mm above the cushioning material. The flow of air augmented the oxygen supply, but the times to ignition were increased over the previous tests due to the cooling effect of the air stream. As shown in Table VIII, under the modified test the fire-retardant rubberized curled hair was significantly better than the vegetable fiber cushioning material, requiring between 85 and 90 seconds of heating to ignite the propellant compared to the 25 to 30 seconds for the ordinary vegetable fiber. Vegetable fiber cushioning material that had been made fire-retardant by a 1-minute immersion in a neutral ammonium phosphate solution was also tested. The treated vegetable fiber was superior to the untreated fiber in respect to preventing ignition of the propellant grains, though the treated vegetable fiber was not as good as the fire-retardant curled hair. The results indicate that with fire-retardant cushioning the propellant "cooks-off" due to heat transfer. With ordinary cushioning material, in the presence of adequate oxygen, the flame from burning cushioning material ignites the propellant. Less heat is required to initiate the burning of cushioning material than is needed for the propellant to reach cook-off temperature by heat transfer.

B. Small Scale Test Results

When the propellant in a donor charge was ignited, flame would "blowtorch" from the open end of the can intermittently as the fire progressed from one increment (zone charge) to another. The duration of one "spurt" of flame was proportional to the size of the increment that was burning. The flame from a burning donor charge completely enveloped the acceptor cans in all cases.

Table VII. Insulating Properties of Cushioning Materials for Packaging of Ammunition*

	Untreated Vegetable Fiber	Fire-Retardant Vegetable Fiber**	Fire-Retardant Curled Hair
	Time, in seconds		
Time of heating when applied until propellant ignites.	102	105	101
Maximum time heat could be applied without ignition of propellant.	25	70	85
Minimum time of heating for ignition of propellant			
Heating time	30	72	90
Time at which propellant ignited	166	150	100

Tested with a stream of air applied to propellant and cushioning material.

**Treated with ammonium phosphate solution.*

There was relatively good agreement between the results of the small scale tests, see Table VII, and the laboratory test results in Tables II, III, and V. The differences between the two sets of test results can be attributed to differences in heat absorption, heat transfer to the propellant and heat loss due to radiation.

These test results show that cook-off times can be increased by either 1) painting the exterior surfaces of the cans with two coats of intumescent paint and treating the inner wrap, 2) painting the exterior surfaces with three coats of paint, or 3) insulating the propelling charge from the metal can with six layers of treated corrugated inner wrap.

C. Large Scale Test Results

An intense propellant fire followed the static detonation of the 81-mm mortar projectile, see Figure 7. The fire completely enveloped the center of the target array in all three tests.

The results of these tests, see Table VIII, correspond to those of the small scale tests. That is, cook-off reactions were observed following the initial propellant fire in Test No. 1 (unmodified pallets and shipping cans) and were not observed when modified shipping cans and non-combustible pallets and dunnage were used in Tests No. 2 and 3.

The post test "body count" reported for Tests 2 and 3 is an approximation. No attempt was made between Tests 2 and 3 to repair the damage to the target array, replace any damaged cans or inspect the condition of the treated paperboard inner wrap of those charge cans that survived. However, it was observed after Test No. 2 that the intumescent paint on most of the cans did react to the heat from the burning propellant producing a relatively fragile char. It is assumed that this char was dislodged when the mortar projectile was detonated in Test No. 3. If this was the case, then many of the cans in Test No. 3 were tested without the full thermal protection of the intumescent paint.

IV. CONCLUSIONS

The cook-off characteristics of 155-mm MA42 propelling charges can be improved (extended) by painting the exterior surfaces of their metal shipping cans with intumescent paint and/or treating all combustible inner wrap materials chemically so that they are fire-retardant.

Improving the cook-off characteristics of separate-loading propelling charges can limit the extent of damage to multi-pallet stores when they are subjected to direct hits by large caliber HE projectiles. However, both the propelling charges and the combustible wooden pallets and dunnage must be treated if the effort is to be worthwhile.

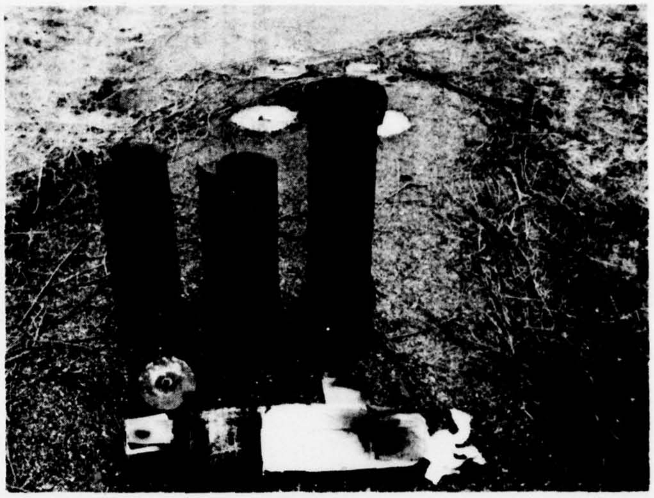
Table VIII. 155-mm Cook-Off Test Results of M4A2 Propelling Charge

TEST NO.	DONOR MODEL	STANDOFF (CM)	BURN TIME(s)	ACCEPTOR CONFIGURATION	ACCEPTOR COOK-OFF	REMARKS
1	M3	10	12	One can	No cook-off	
2	M4	30	35	Ten cans. Four live - six inert.	No cook-off	
3	M3 (2 ea)	10	12	One can.	No cook-off	Two M3 donor charges were ignited simultaneously.
4	M4A2 (2 ea)	46	33	Three cans. Two live - one inert.	One at 40 sec. Other acceptor did not cook-off.	Second donor ignited 10 seconds after first donor.
5	M4A2	46	35	Same as Test No. 4.	One at 72 sec. Other acceptor did not cook-off.	Same as Test No. 4.
6	M4A2	46	35	Three cans. One live - two inert.	37 sec.	Same as Test No. 4.
7	M4A2	46	31	Same as Test No. 6.	35 sec.	Same as Test No. 4.
8	M4A2	46	30	Same as Test No. 6.	No cook-off	Acceptor can painted with two coats of intumescent paint. Inner wrap materials treated and made fire retardant. Post test inspection revealed that inner wrap materials and cloth bags were scorched.

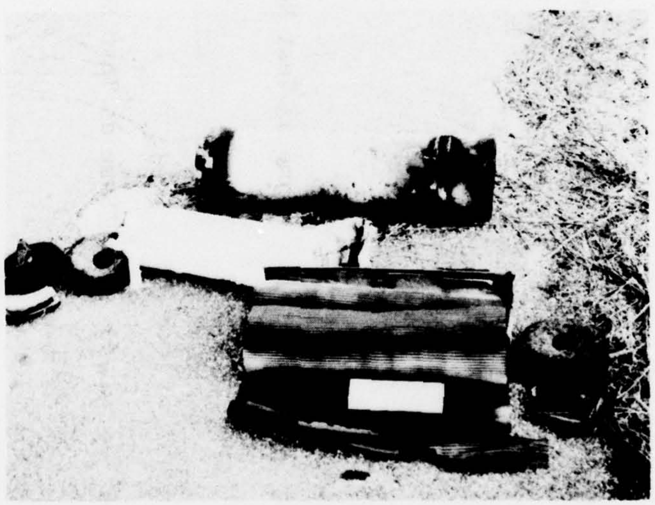
Table VIII. 155-mm Cook-Off Test Results of M4A2 Propelling Charge (Continued):

TEST NO.	DONOR MODEL	STANDOFF (CM)	BURN TIME(s)	ACCEPTOR CONFIGURATION	ACCEPTOR COOK-OFF	REMARKS
9	M4A2	46	33	Same as Test No. 6.	No cook-off	Same as Test No. 8.
10	M4A2 * (2 ea)	46	45	Same as Test No. 6.	No cook-off	Same as Test No. 8.
11	M4A2 (2 ea)	45	45	Same as Test No. 6.	No cook-off	Acceptor can painted with three layers of paint. Inner wrap materials were untreated. Post test inspection revealed that the inner wrap materials and cloth bags were scorched.
12	M4A2 (2 ea)	45	45	Same as Test No. 6.	45 sec.	The inner wrap materials were treated and made fire retardant. The outside of the can was unmodified.
13	M4A2 (2 ea)	45	45	Same as Test No. 6.	No cook-off	The inside diameter of the acceptor can was increased by approximately 25mm to provide space for six layers of fire retardant paper. The outside of the can was not painted.

* *To increase donor burn time, two M4A2 charges were placed, in tandem, in a long propellant charge can. This configuration was used in Tests 10-13.*

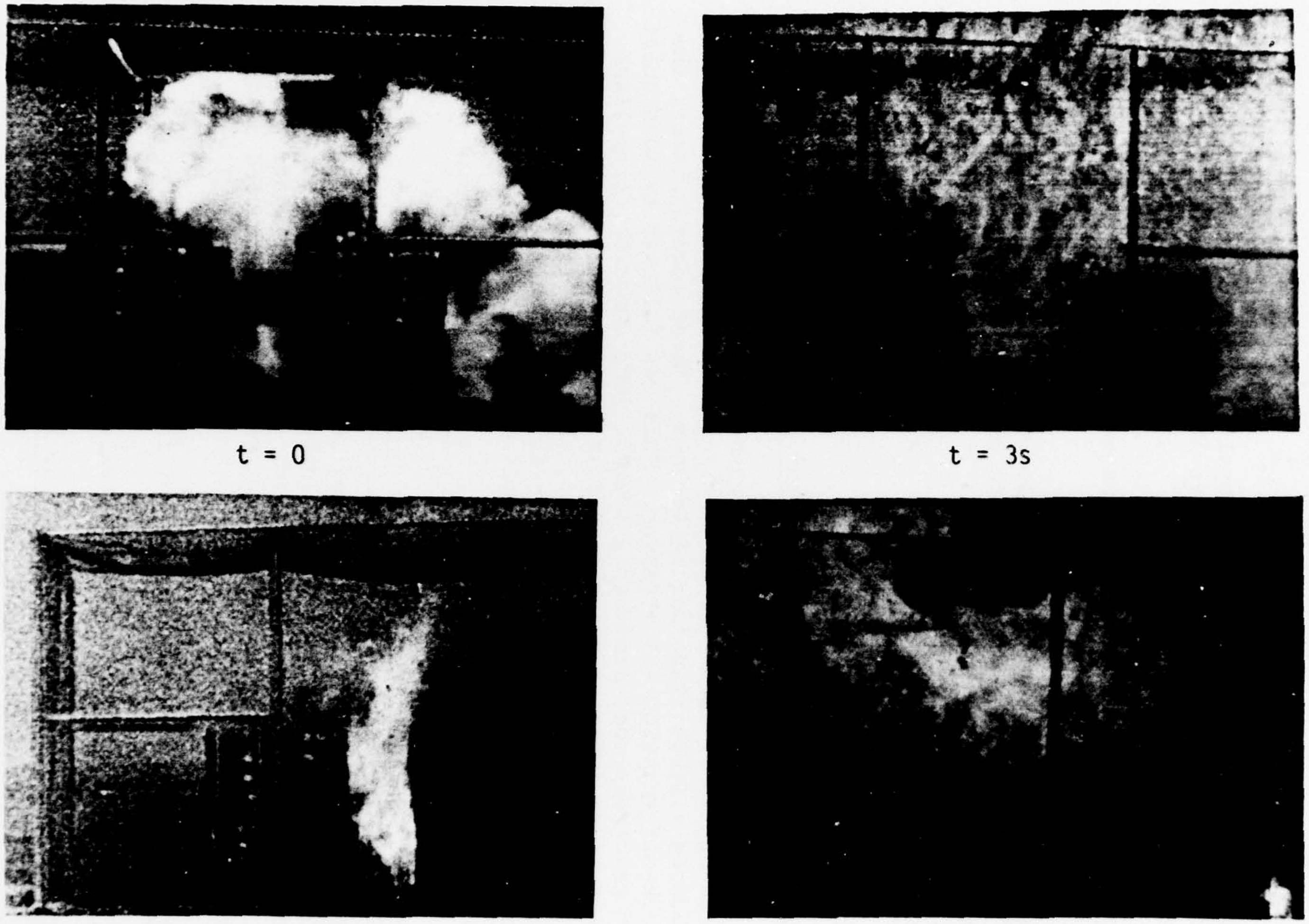


Test No. 10



Test No. 13

Figure 6. Small Scale Test Results



t = 0

t = 3s

t = 30s

t = 60s

Figure 7. Test No. 1 - 81mm Mortar Projectile vs Palletized 155mm Propelling Charges.

Table IX. 81-mm Mortar Projectile Versus Palletized 155-mm M4A2 Propelling Charges

TEST NO. 1

Target Array: A total of 160 M4A2 propelling charges positioned in the center of a 16-pallet array (see Figure 4). The remaining cans in the array were sand-filled.

Modifications: Sand-filled charge cans were secured, without dunnage, to metal pallets.

Duration of Fire: Propellant fire observed for 5.5 min. The wooden pallets and dunnage used with the "live charges" continued to burn for approximately 45 min.

Time to First Cook-Off: 37 seconds

Total Number of Cook-Offs: 125

Total Number of Cans Destroyed by Mortar Projectile: ≃ 35

Remarks: An intense propellant fire observed following the static detonation of the 81-mm mortar projectile, see Figure 7. This initial fire produced visible flame for 34 seconds. Three seconds later, the first cook-off reaction was observed. This was followed by subsequent cook-off reactions that produced a second, long duration, propellant fire. Post test inspection revealed that a total of 35 cans were damaged by the mortar projectile, i.e., they were either blown apart of perforated by fragments, see Figure 10. The remaining 125 live cans were recovered without closing lids or propellant charges.

TEST NO. 2

Target Array: Same as TEST NO. 1.

Modifications: Sand-filled charge cans were secured, without dunnage, to metal pallets. Propellant-filled donor cans were painted with two coats of intumescent paint and contained fire-retardant inner wrap. Pallets and dunnage used to secure live cans were constructed using fire-retardant wood.

Duration of Fire: 35 second propellant fire.

Time to First Cook-Off: No cook-off reactions observed.

Total Number of Cans Destroyed by Mortar Projectile: ≃ 35

Table IX. 81-mm Mortar Projectile Versus Palletized 155-mm M4A2 Propelling Charges (Continued):

Test No. 2 (Continued):

Remarks: An intense propellant fire observed following the static detonation of the 81-mm mortar projectile. Fire went completely out in 35 seconds. No cook-off reactions or burning wood observed. Post test inspection indicated that approximately 35 live cans were damaged by the mortar projectile. An exact count was not possible since the target array was left as is for Test No. 3.

TEST NO. 3

Target Array: Target array from Test No. 2 was used in an as found condition. No attempt was made to repair the damage to the target array or replace damaged cans. Mortar projectile position was moved to the opposite row of live pallets and raised to a height of 1.5 metres above the ground.

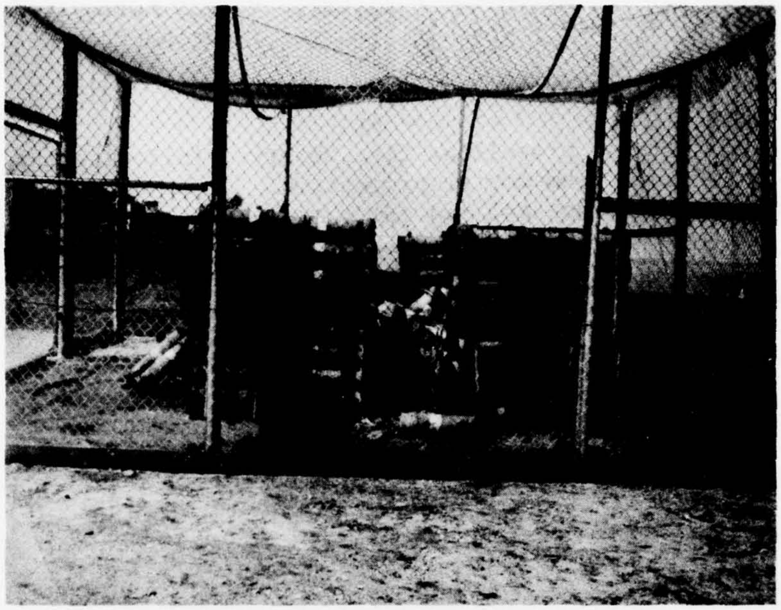
Modifications: Same as TEST NO. 2.

Duration of Fire: 30 second propellant fire.

Time to First Cook-Off: No cook-off reactions observed.

Total Number of Cans Destroyed by Mortar Projectile: ≃ 20

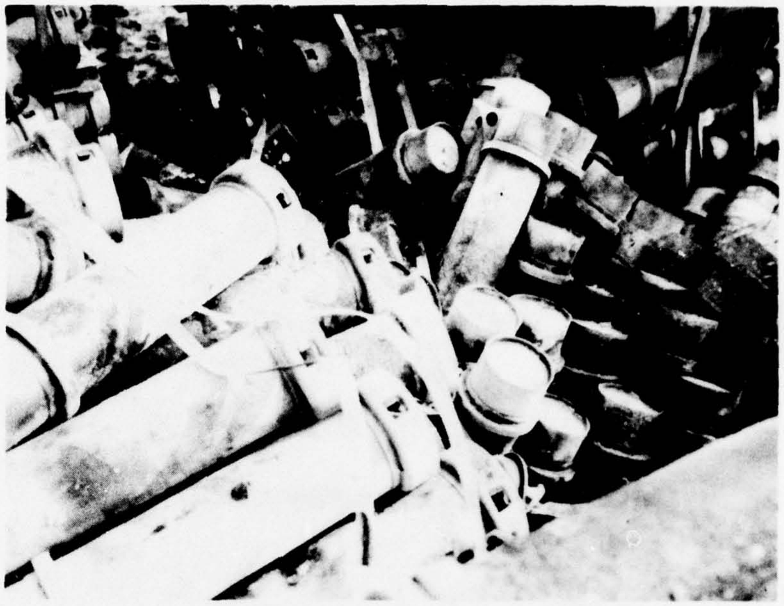
Remarks: An intense propellant fire observed following the static detonation of the mortar projectile. Fire went completely out in 30 seconds. No cook-off reactions or burning wood observed.



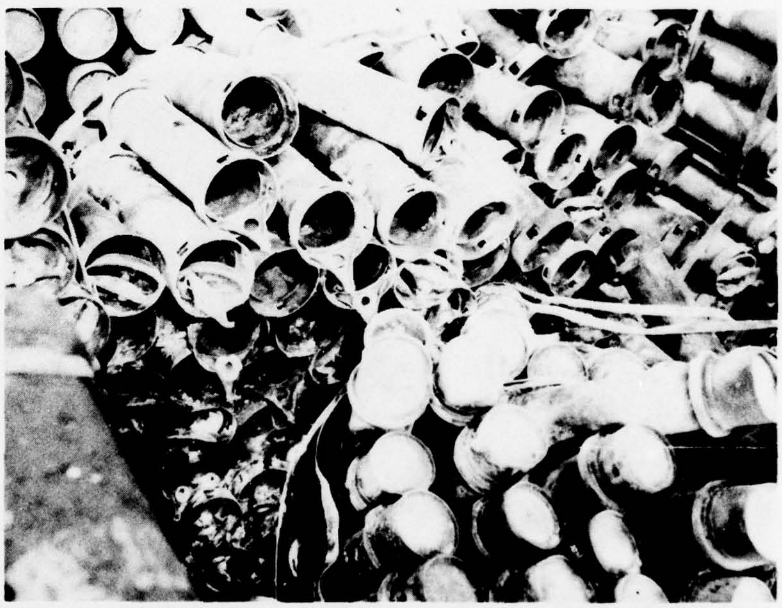
Side View

Rear View

Figure 8. Test Results - Large Scale
Test No. 1



Top View from Right Side



Top View from Rear

Figure 9. Test Results - Large Scale
Test No. 1

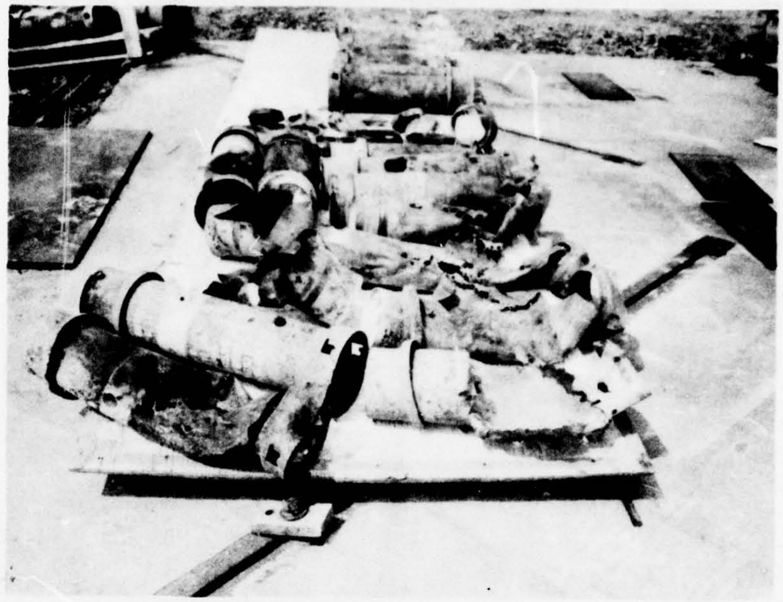


Figure 10. Test Results - Large Scale

Test No. 1. Cans Destroyed by Mortar Projectile

The treatments evaluated in this study will all fail (thermally decompose) when subjected to a long duration heat source. Standard wooden pallets and dunnage, ignited by burning propellant, can provide a long duration heat source.

The correspondence between the results of the laboratory, small scale and large scale tests demonstrates the validity of ranking, via laboratory tests, the effectiveness of other candidate treatments and materials that may be more desirable in terms of cost, performance, and durability.

Modification techniques that are effective in improving the cook-off characteristics of M4A2 charges can be used successfully with other separate-loading charges.

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